

HIGH TEMPERATURE OXIDATION BEHAVIOUR OF ALUMINIZED COATINGS ON GREY CAST IRON FABRICATED BY HOT-DIPPING IN A PURE AL OR AISi11 BATH

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Abstract

This paper investigates the oxidation behaviour of aluminized flake graphite cast iron. Aluminized coatings were fabricated by hot-dipping cast iron in a pure Al or AISi11 bath at 750 °C for 20 min. The microstructure analysis showed that both types of coatings consisted of two layers: an outer layer with a composition similar to that of the aluminized bath and an inner layer with intermetallic phases. Dispersed flakes of graphite were observed in both layers. The coatings fabricated in AISi11 were thicker than those produced in pure Al. High temperature oxidation tests of aluminized and bare cast iron samples were conducted over a period of nineteen 24-hour cycles. It was shown that flake graphite cast iron hot-dip coated with pure Al or AISi11 alloy exhibits comparable resistance to cyclic oxidation to uncoated cast iron.

Keywords: Hot-dip aluminizing, flake graphite cast iron, intermetallic phases, microstructure, high temperature oxidation resistance

1. INTRODUCTION

Aluminizing is a process in which the surface of a metallic material is coated with a layer of aluminium. Steels and cast irons are the most common materials that are aluminized, but this process is also used for nickel, copper, titanium and magnesium alloys [1-4]. Aluminium coatings on steel or cast iron are applied to increase their heat resistance and corrosion resistance [5-7]. Various methods are applied to fabricate aluminium coatings. Hot-dip aluminizing is a technique that is relatively cheap and simple. In this process, the components to be coated are dipped in a pure aluminium bath or in an aluminium alloy bath (Al-Si [8,9], Al-Zn [10] or Al-Ti [11]). The thickness and the structure of aluminized coatings depend on the type of the dipped material and its temperature, the chemical composition and temperature of the bath, and the holding time [8].

In this study, grey cast iron was aluminized by hot-dipping in a pure Al or Al-Si alloy bath. The high-temperature oxidation behaviour of coated and uncoated samples was analyzed. The microstructures of the coatings and the bare substrate before and after the oxidation test were also examined.

2. EXPERIMENTAL DETAILS

EN-GJL-200 pearlitic flake graphite cast iron was used as the substrate material. Before dipping, the surfaces of the samples were ground with 800-abrasive paper and cleaned with ethanol. Hot dip aluminizing was performed using a Nabertherm 2/13 melting furnace furnished with a graphite crucible. The samples were immersed in a molten bath of pure aluminium (A1) or AISi11 alloy at 750 °C for 20 min. The chemical compositions of the aluminium alloys are given in **Table 1**.

Table 1 Chemical compositions of the alloys used for hot-dip aluminizing

Alloy	Al	Si	Fe	Mn
	[wt. %]			
A1	min. 99.50	max. 0.25	max. 0.40	max. 0.05
AlSi11	85-88	10-13	0.8	0.5

The oxidation tests were performed using 24-hour heating cycles, after which the samples were cooled down to room temperature and weighed by analytical balance (0.0001 g accuracy). After 8 cycles of heating (192 h) the heating temperature was raised to 700 °C due to no significant changes in the oxidation process. At this temperature, 11 cycles of heating (264 h) were performed. The microstructure analysis of the aluminized samples was conducted using a Nikon ECLIPSE MA 200 optical microscope and a JEOL JSM-5400 scanning electron microscope equipped with a LINK ISIS 300 energy dispersive X-ray spectrometer.

3. RESULTS AND DISCUSSION

The microstructures of the flake graphite cast iron aluminized in pure Al or AlSi11 alloy are shown in **Fig. 1**. In both cases, the coating consists of an outer layer and a thin transition zone between the substrate and the outer layer. Flakes of graphite are clearly visible in the coatings. From the comparison the microstructures, it is evident that the coating produced in pure aluminum (**Fig. 1a**) is thinner than that obtained in the AlSi11 alloy (**Fig. 1b**).

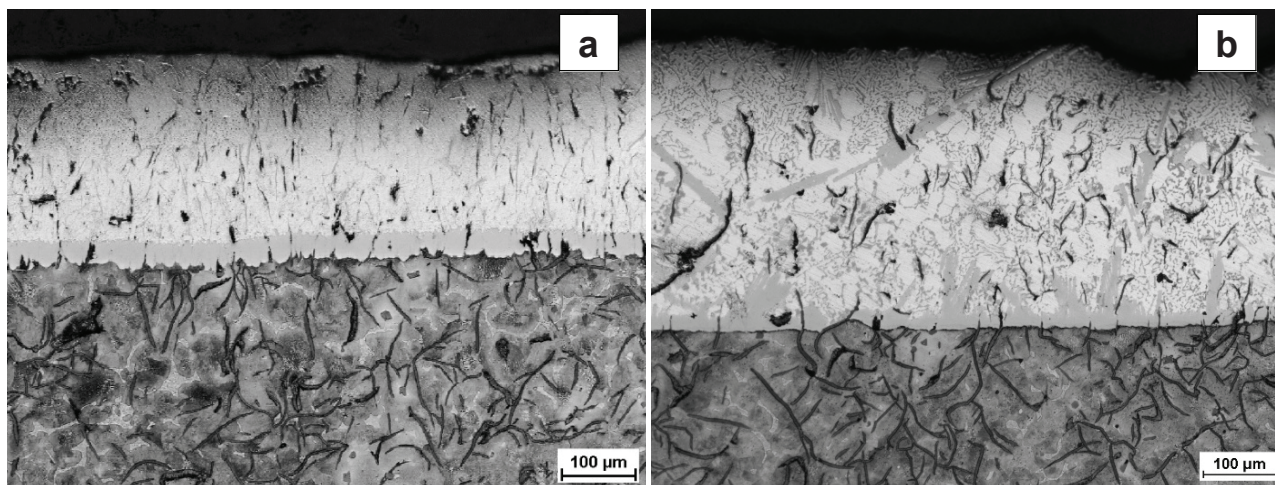

Fig. 1 Optical microphotographs of cast iron hot-dip coated with: a) pure aluminium, b) AlSi11 alloy

Fig. 2 shows the microstructures of the transition zones observed at a higher magnification. The transition zone in the coating fabricated by hot-dipping in pure aluminium (**Fig. 2a**) is thicker and more regular compared with that obtained in AlSi11 alloy (**Fig. 2b**). The transition zone observed in the sample aluminized in pure aluminium exhibits a tongue-like morphology at the interface with the cast iron substrate. A regular interface was observed in the area adjacent to the outer layer. In the sample aluminized in AlSi11 alloy, the interface between the transition zone and the cast iron was nearly flat and the interface with the outer layer was much more irregular.

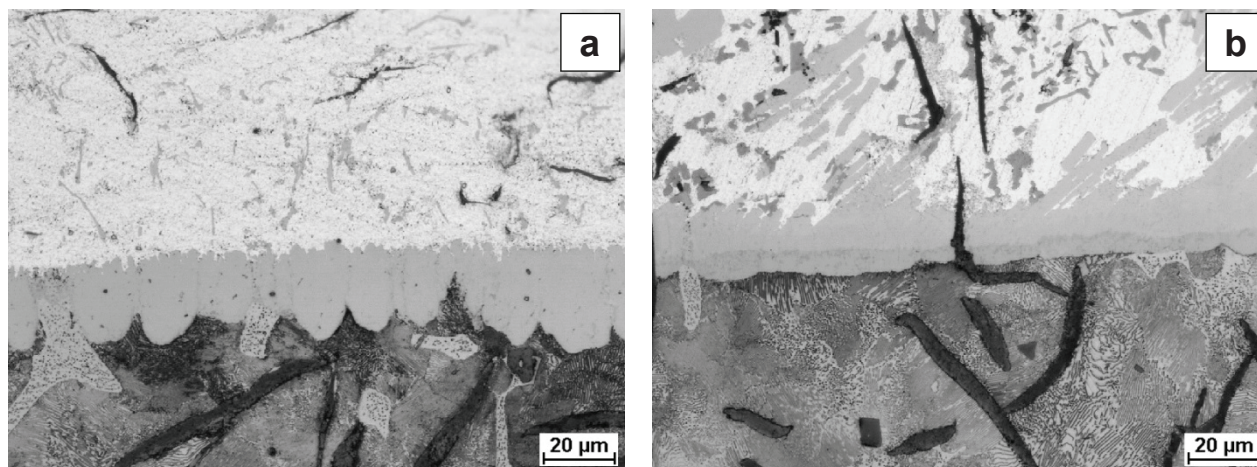


Fig. 2 The microstructures of the transition zones in the coatings aluminized in: a) pure aluminium, b) AlSi11 alloy

High magnification SEM images of the transition zones are presented in **Fig. 3**. In both examined coatings two layers can be distinguished in the inner transition zone. The EDS analysis in this zone of the sample coated in pure aluminium indicated that the thicker layer (marked A in **Fig. 3a**), adjacent to the cast iron substrate, contained: 71.50 at.% Al, 25.75 at.% Fe and 2.75 at.% Si. This suggests the presence of the Al_5Fe_2 phase with a small amount of Si. The occurrence of silicon in this zone was due to the presence of this element in the cast iron substrate. The composition of the thinner layer (marked B in **Fig. 3a**) was: 79.51 at.% Al, 19.62 at.% Fe and 0.87 at.% Si, which corresponded to the Al_3Fe phase. For the sample aluminized in the AlSi11 alloy, the EDS point analysis was performed at the points marked in **Fig. 3b**. The thinner layer (marked A) comprised 70.37 at.% Al, 26.04 at.% Fe and 3.59 at.% Si. This result indicates the Al_5Fe_2 phase. The chemical composition of the area marked C (66.39 at.% Al, 17.03 at.% Si and 16.58 at.% Fe) suggests the presence of the Al_5FeSi phase. The plate-shaped phases randomly distributed in the outer layer of the coating (marked D) had a similar composition, i.e. 67.76 at.% Al, 18.14 at.% Si and 14.10 at.% Fe.

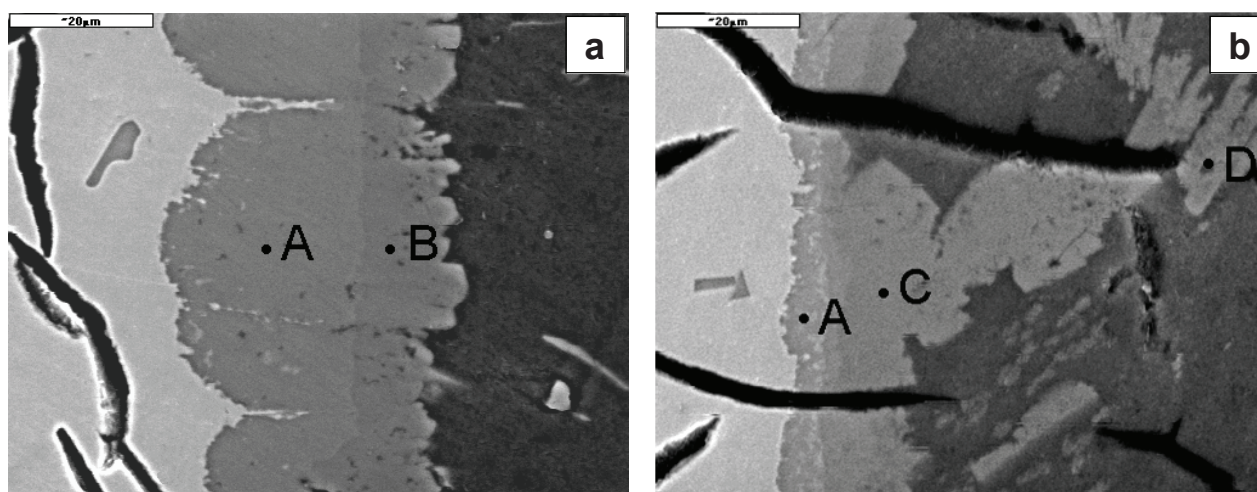


Fig. 3 SEM microphotographs of the transition zones in the coatings aluminized in: a) pure aluminium, b) AlSi11 alloy

The high temperature oxidation kinetics of the coated specimens and the bare grey cast iron was studied first at 650 °C for 192 h and then at 700 °C for 264 h. Twenty-four-hour cycles of heating were applied. The weight changes in the function of exposure time for the aluminized and uncoated cast iron specimens are shown in

Fig. 4. It can be seen that all the examined specimens gained weight with an increase in the heating time. The oxidation rates for cast iron aluminized in both baths are similar to those observed for uncoated cast iron. Increasing the temperature from 650 °C to 700 °C after eight 24 h cycles caused no significant changes in the oxidation behaviour of the tested specimens and there was a continuous weight gain. An increase in the weight resulted from the formation of corrosion products during annealing. No spalling of corrosion products during the repeated cycles of annealing and cooling for all the tested specimens was observed.

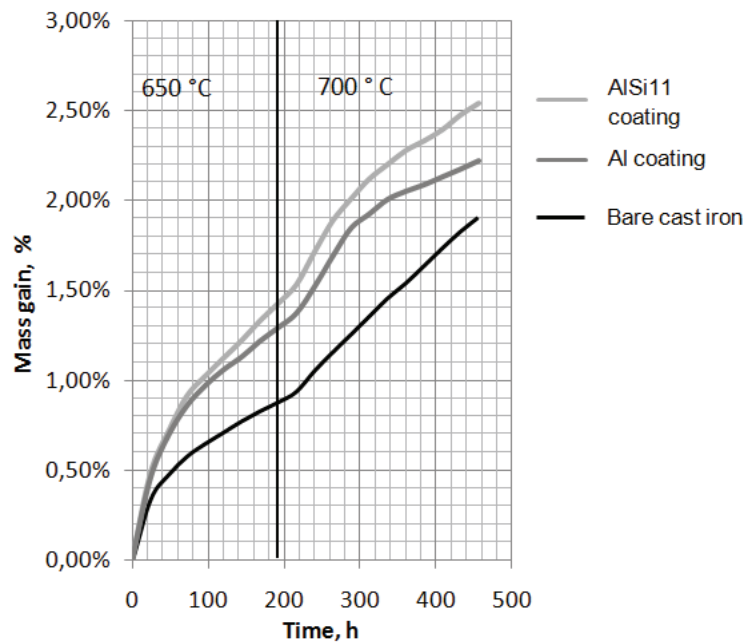


Fig. 4 Weight gain curves of the aluminized and bare grey cast iron specimens

The cross-sections of the uncoated cast iron and hot-dip aluminized specimens after the oxidation tests are shown in **Fig. 5**. The surface of cast iron is covered with an oxide layer 250 µm in thickness (**Fig. 5a**). **Fig. 5b** shows the microstructure of the cast iron aluminized in pure aluminium after oxidation. A thin, light layer of the remaining aluminium coating is observed in the top zone. Underneath there is a visible oxide layer. Between the oxide layer and the substrate a dark zone is observed. the coating on grey cast iron fabricated in AISi11 alloy (**Fig. 5c**). The coating on grey cast iron fabricated in AISi11 alloy (**Fig. 5c**) has a similar structure after cyclic heating.

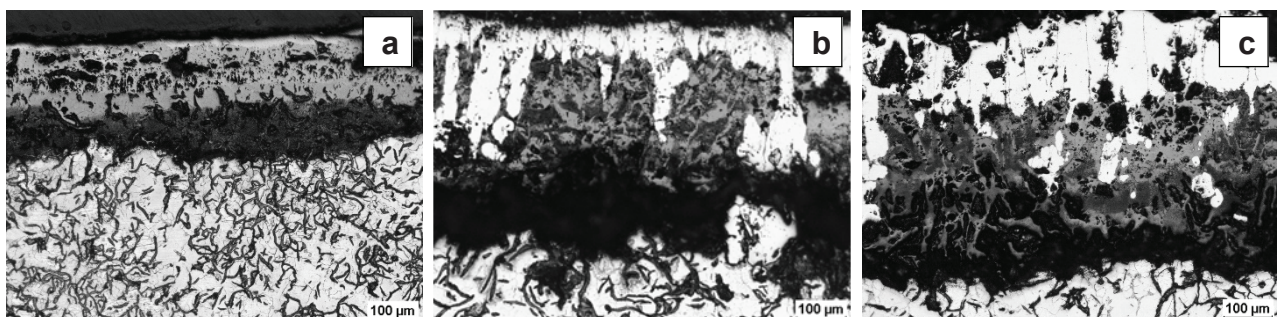


Fig. 5 Optical microphotographs of cast iron after the high temperature oxidation behaviour test: a) bare, b) coated with pure aluminium, c) coated with AISi11 alloy

Fig. 6 shows SEM images of the specimens aluminized in pure aluminium or AISi11 alloy after the oxidation test. The distributions of C, O, Al, Si and Fe along the index line are also presented in this figure. The linear

analysis shows that carbon is present in the dark zones adjacent to the cast iron substrate. The high concentration of oxygen and iron in the middle, grey zone confirms the occurrence of the iron oxide layer. The linear analysis also indicates the presence of aluminium in the outer zone in both coatings, which suggests that after 456 h of oxidation the aluminium or aluminium-silicon outer layers were not consumed completely.

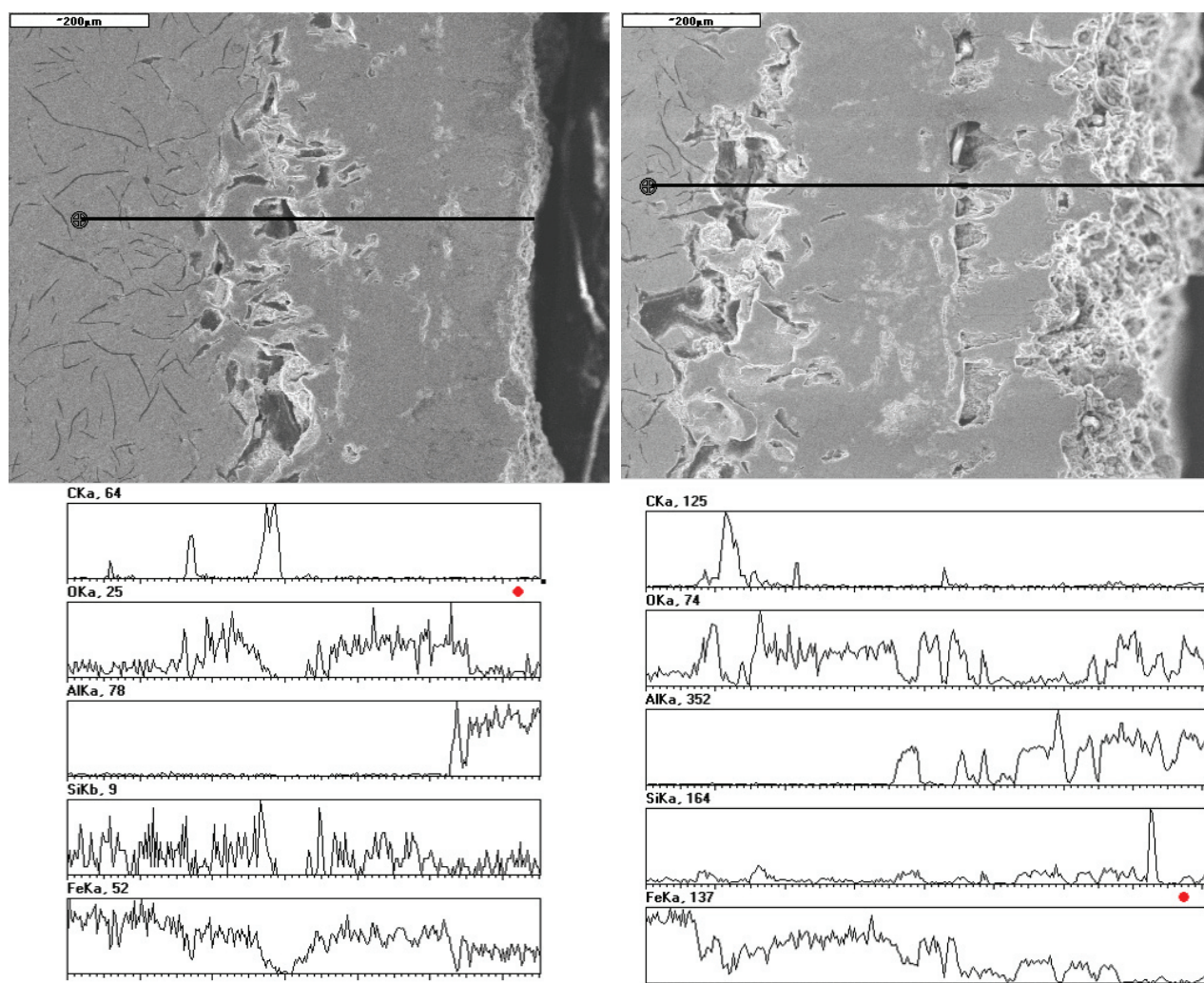


Fig. 6 SEM microphotographs of the coating aluminized in: a) pure aluminium, b) AISi11 alloy after 456 h annealing and the corresponding EDS spectra

These results show that aluminized flake graphite cast iron did not exhibit better oxidation resistance than bare cast iron. This can be explained as follows. During the cyclic annealing process the flakes of graphite trapped in the aluminium coating oxidize rapidly. This leads to the formation of cracks in the coating. The cracks are paths along which oxygen penetrates into the substrate. An iron oxide layer forms on the cast iron substrate keeps growing as the oxidation time increases. The surface of the cast iron in contact with oxygen becomes skin decarburized and thin layers of carbon form below the oxide layer [5,6].

4. CONCLUSIONS

The coatings fabricated on flake graphite cast iron by hot-dipping in pure Al or AISi11 alloy consisted of an outer layer, an inner Fe-Al intermetallic layer and dispersed flakes of graphite. The coatings produced in an AISi11 alloy bath were thicker than those obtained by the application of a pure aluminium bath.

The cyclic oxidation tests show that the weight gains of the specimens with aluminium coatings produced in both baths were similar to that of the bare flake graphite cast iron. Furthermore, there was no difference in oxidation behaviour between specimens hot-dip coated with pure aluminium and those produced in the AlSi11 bath. The graphite flakes dispersed in the aluminium coatings oxidize rapidly at high temperature which leads to crack propagation in the coating. The cracks allow oxygen penetration through the coating to the substrate and its oxidation. The results indicate that aluminium coatings on flake graphite cast iron do not prevent oxidation of the substrate at temperatures of above 650 °C.

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